INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: METHOD FOR INDEPENDENTLY CONTROLLING THE WAVELENGTH COMPONENT POWERS IN AN OPTICAL WAVELENGTH DIVISION MULTIPLEXED TRANSMISSION SYSTEM
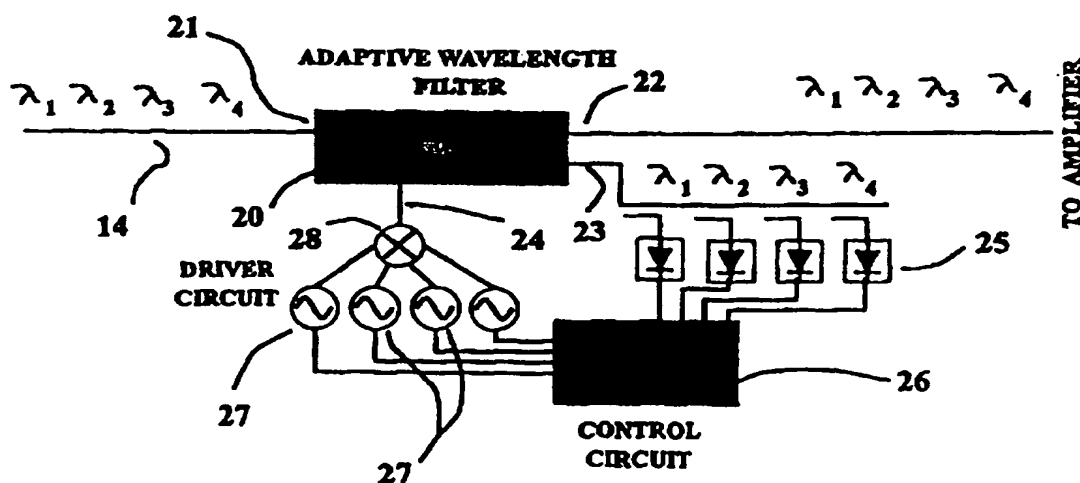
(57) Abstract

A method of and apparatus for controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal (14) employs an adaptive optical wavelength filter (20) through which the optical signal (14) is transferred. The filter (20) is controlled dependent upon an analysis of the powers of the individual wavelength components (λ_1, λ_2...) of the optical signal so that the output powers may be balanced to have some predetermined relationship. One of a plurality of in-line optical filters, a demultiplexer and a further adaptive optical wavelength filter may be employed to analyse the powers of the wavelength components of the optical signal.

METHOD FOR INDEPENDENTLY CONTROLLING THE WAVELENGTH COMPONENT POWERS IN AN OPTICAL WAVELENGTH DIVISION MULTIPLEXED TRANSMISSION SYSTEM

This invention relates to a method of and apparatus for controlling the relative amplitudes of the individual wavelength components of a wavelength division multiplexed optical signal.

5   The use of wavelength division multiplexing on optical communications systems is rapidly expanding in order to increase the information carrying capacity of a system. In addition, such multiplexing also allows the provision of network switching and protection
10   functions in an effective and economic manner. A wavelength division multiplexed optical signal propagated along optical fibre carries several channels at different wavelengths.   At transmission, the wavelength component for any one channel normally has
15   the same amplitude as that of the other channels, but as these wavelength components are processed through a network, the relative amplitudes of the channels become unbalanced.

The optical power per channel at key points in a
20   network will vary depending upon the path taken to reach a given key point. Moreover, the optical power will vary dynamically should network reconfiguration or re-routing take place. Any initial wavelength imbalance in a transmitter will exacerbate the
25   variation in channel optical power following processing of the optical signal through the network.

A further problem is that a typical optical amplifier has a non linear transfer function, in that the gain varies dependent upon the wavelength being
30   amplified. If a wavelength division multiplexed optical signal is passed through such a non linear amplifier, any imbalance in the input signal will be worsened, so degrading the network performance.

The present invention aims at providing both a
35   method of and apparatus for addressing the difficulties

arising from optical power variation across the
channels of a wavelength division multiplexed optical
signal consequent upon the propagation of the
wavelength components of that signal through a network.

5   According to one aspect of the present invention,
there is provided a method of controlling the relative
amplitudes of the individual wavelength components of a
wavelength division multiplexed optical signal, in
which method the wavelength division multiplexed

10   optical signal is processed through an adaptive optical
wavelength filter, the relative powers of each
wavelength component of the optical signal are
determined, and a complex control signal is supplied to
the adaptive optical wavelength filter which control

15   signal includes a control component for each wavelength
component of the multiplexed optical signal, the
magnitude of each control component being adjusted
dependent upon the determined power of the respective
optical signal wavelength component.

20   The present invention makes use of the transfer
characteristics of an adaptive optical wavelength
filter, known per se. Embodiments of such filters
include acousto-optic and electro-optic tunable
filters.   In the case of either of these types of

25   filter, there is an optical waveguide for an optical
signal and the transfer function for an optical signal
is defined by virtue of a stress-induced birefringence.
The interaction between the optical signal and the
stressed waveguide results in a polarisation conversion

30   of the optical signal. As a result, if polarisation
selective elements are added before and/or after the
interactive section of the filter, the passband on the
(or each) output port of the filter will be governed by
whether polarisation conversion has occurred.

35   In the case of an acousto-optic filter, the
stress-induced birefringence is defined by injecting

into the filter a lower frequency waveform, i.e.
electromagnetic energy typically in the range of a few
hundred MHz.   In the case of an electro-optic filter,
the birefrigence is induced by an electrode structure
5   arranged along the wave guide.

An adaptive optical wavelength filter as described
above allows for the selective addition or subtraction
of a wavelength division multiplexed channel from an
optical communication network.   The simultaneous
10   addition or subtraction of multiple channels can be
achieved by the use of an appropriately configured
filter of this kind.

The two types of adaptive optical wavelength
filter usually employed in optical networks are known
15   as acousto-optic and electro-optic tunable filters.   In
the former, a relatively low frequency control signal
is applied to the filter, and in the latter, a d.c.
control signal is applied to the filter electrode
structure, there being a separate electrode structure
20   for each channel.   Either kind of filter may be used in
the present invention.   Both kinds of filter may be
configured to have more than one output port and it is
preferred to use such a filter, with the channel power
determination being performed on the output from one
25   port, and the principal optical signal being propagated
from the other output port.   Conveniently, for the
generation of an appropriate control signal,   the
output at said one port is the inverse of the output at
said other port.   Alternatively, the filter may have a
30   single output port and the channel power determination
is performed on the optical signal obtained from a
passive tapping on the output from that port.

In performing the method of this invention,
consideration must be given to the locking, in terms of
35   absolute wavelengths, of the filter performing the
adaptive filtering and the elements performing the

determination of power levels within the different
channels to define the adaption required in the filter.
A 'window' could be set, which would be a fraction
(perhaps 40%) of the channel separation between the
5   channels.   The optical signals transmitted may
therefore be anywhere within this 'window' for each
channel, and so both the optical filter and the network
will need fairly broad responses to these 'windows'.
As a result, the filter and channel power determining
10   elements (analyser) will need to be locked tightly only
if the responses are well matched.   A more relaxed
locking requirement would be possible if the analyser
has slightly wider 'windows' than the filter.   In a
case where the analyser takes the form of a passive
15   demultiplexer, this may be achieved by changing the
specification of the filters and other components
within the demultiplexer.   Alternatively, where the
analyser comprises a second active filter, a small
design change to widen the filter response may be all
20   that is required to achieve a relaxed locking
regime, as both filters would, in such an arrangement,
be locked to the same driver circuit.

The transmission standards for an optical
communication network define specific centre
25   wavelengths for the network.   Consequently, no locking
of the adaptive filters to each other, across the
network, should be required.

According to a second aspect of the present
invention, there is provided apparatus for controlling
30   the relative amplitudes of the individual wavelength
components of a wavelength division multiplexed optical
signal, which apparatus comprises an adaptive optical
wavelength filter through which the optical signal is
passed for processing therein, means to determine the
35   relative powers of the wavelength components of the
processed optical signal, control means responsive to

the determined powers of each wavelength component and
providing a complex control signal to the adaptive
optical wavelength filter which complex control signal
includes a control component for each wavelength

5   component of the multiplexed optical signal, the
control means controlling the magnitude of each
control component dependent upon the determined power
of the respective optical signal wavelength component.

In the present invention, the complex control

10   signal has a control component for each wavelength
channel of the optical signal, the energy or magnitude
of each such component being controlled dependent upon
the detected power of each wavelength component of the
optical signal. In order to achieve a closed loop

15   feedback system, the relative powers of the individual
wavelength components of the optical signal should be
determined following the processing of that signal in
the adaptive optical wavelength filter.

When an acousto-optic tunable filter is employed,

20   the control signal will have a frequency component for
each channel of the optical signal, the energy of each
such frequency component being adjusted in order to
control the power of the respective wavelength
component of the optical signal. If an electro-optic

25   tunable filter is employed, the control signal will
have a d.c. component for each channel of the optical
signal, each d.c. component being applied to the
respective electrode structure of the filter to control
the power of the respective channel of the optical

30   signal, dependent upon the voltage of the applied d.c.
control component.

The determination of the power of each channel of
a wavelength division multiplexed optical signal may be
performed by any suitable manner known in the art. For

35   example, in-line optical filters may be employed to
separate a portion of the optical signal into its

individual wavelength components, the amplitude of each of which then being determined for instance by an individual photo-detector for each channel. Instead of the use of optical filters, a wavelength division

5   demultiplexer may be employed to separate a portion of the optical signal into individual wavelength components.

The determination of the power of each channel of the optical signal may instead be determined by a

10 further adaptive optical wavelength filter similar to that employed to control the magnitude of each wavelength component of the optical signal. Such a further filter may sample each channel of the optical signal, in sequence, the output of the further

15 filter sequentially corresponding to the power of each channel of the optical signal. By linking the two filters to the same driver circuit, the operation of the two filters will be closely locked to each other and the signal wavelengths being analysed. With this

20 arrangement, the two filters could be arranged on one integrated circuit.

The magnitude of each control component of the control signal may be adjusted such that the relative powers of each wavelength component of the optical

25 signal are, after processing in the filter, substantially the same. Alternatively, when the processed optical signal is subsequently to be processed through a non-linear component such as an optical amplifier, each control component of the

30 control signal may be adjusted having regard to the transfer function of the subsequent non-linear component. In this way, the power of all wavelength channels of the optical signal may be controlled so as to be essentially the same, following processing

35 through the non-linear component.

By way of example only, the invention will now be

described in greater detail and certain specific examples thereof given, reference being made to the accompanying drawings, in which:-

Figure 1 schematically shows a network for the processing of wavelength division multiplexed optical signals;

Figure 2 diagrammatically illustrates a first example of a method of this invention;

Figure 3 diagrammatically illustrates a second example of a method of this invention, similar to that of Figure 2;

Figure 4 diagrammatically illustrates a third example, using a filter to analyse the channel wavelengths;

Figure 5 illustrates yet another example, similar to that of Figure 4;

Figure 6 shows the transfer function of an adaptive filter, showing the slewing of power between the secondary and main outputs of the filter, as used in the embodiment of Figure 2; and

Figures 7A and 7B compare the output signals from a non-linear optical amplifier, respectively without and with adaptive balancing according to this invention.

Figure 1 diagrammatically illustrates a network including a plurality of switching nodes 10 for optical signals propagated along optical fibres 11. The signals may be multi-channel wavelength division multiplexed signals and so there may be a plurality of wavelengths appearing at any one or more of the nodes 10. For example, fibre 12 may be carrying a channel of wavelength $\lambda 1$ and of amplitude $\alpha 1$, and fibre 13 a channel of wavelength $\lambda 2$ and amplitude $\alpha 2$. If these channels are switched both to appear on fibre 14 as a wavelength division multiplexed signal, though both signals had the same amplitude on entering the network,

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following the processing through the nodes, the relative amplitudes of the two channels will be as shown at a3. Upon subsequent processing of that multiplexed signal, the difference in the amplitudes of
5   the two channels will be exacerbated, leading to possible difficulties in recovering the smaller amplitude channel.

Figure 2 shows the processing of a wavelength division multiplexed signal with channel amplitudes out
10 of balance, such as the signal on fibre 14 of Figure 1. An electro-optic or acousto-optic adaptive filter 20 has an input port 21 and main and secondary output ports 22 and 23 respectively. The filter further has a control port 24. Such a filter is known per se in the
15 art and will not be described in further detail here.

Optical fibre 14 carrying a wavelength division multiplexed signal is connected to the input port 21 and a further fibre to the main output port 22. All of the input channels appear at both the main and
20 secondary ports, but the signal from the secondary port 23 is supplied to a wavelength demultiplexer (not shown, but known per se in the art) in order to provide individual channel components to a group of photo-detectors 25, with one channel component supplied to
25 each photo-detector respectively. The photo-detectors each determine the power of the channel component supplied thereto and in turn provide an output to a control circuit 26. That circuit 26 controls the operation of a plurality of oscillators 27, one
30 oscillator for each wavelength channel of the input signal; the outputs of the oscillators 27 are combined at 28 and supplied to the control port 24 of the filter.

Figure 3 shows an arrangement similar to that of
35 Figure 2, but the adaptive filter 20 has only a main output port 22. The input to the channel power

to that of Figure 4 in that a second adaptive filter 30
is employed to perform the analysis of the multi-
channel signal passing through the filter 20. In this
case, rather than providing two separate sets of
5   oscillators a single set 40 is arranged to control both
filters 20 and 30. For controlling the filter 20, the
outputs from the oscillators are passed through
elements 41 the effective resistance of which can be
varied by the control circuit 32, before the outputs
10 are combined and supplied to the control port 24 of
filter 20. An output is also taken from each
oscillator to a switch circuit 43, the operation of the
switch being performed by the control circuit 32 so
that the appropriate oscillator output is supplied to
15 the control port of filter 30 in a timed relationship
to the operation of the oscillators.

In other respects, the operation of the embodiment
of Figure 5 corresponds to that of Figure 4 and will
not be described further here.

20   Figure 6 shows, for the embodiments any of Figures
2,4 or 5, the relationship between the optical powers
appearing at the main and secondary ports 22 and 23,
for any one wavelength channel of a signal supplied to
the input port 21, when a suitable high frequency
25 control signal is supplied to the control port 24. By
adjusting the energy of the control signal, the
transfer function of the filter for the channel
associated with the frequency of the control signal can
be varied. The power of the output signal at the
30 secondary port 23 is the inverse of the power of the
signal at the main output port 22.

By suitably varying the energy of the control
signal, the power of the optical signal at the main
output port 22 may be controlled to have a desired
35 value. Such control is performed dependent upon the
determined power of the signal from the secondary

output port 23.   The control circuit may thus be configured to define a closed loop system to ensure the power of the optical system at the main output port is maintained constant at a desired value, irrespective of

5   variations in the power of the optical signal at the input port 21.

Figure 7A shows the effect of a typical non-linear optical amplifier 45 on a wavelength division multiplexed optical signal the relative powers of the

10   individual channels of which are as shown at 46.   As can be seen at 47, following processing by the amplifier 45, the relative imbalance in the channel powers is increased.   However, by subjecting the input signal to the amplifier 45 to adaptive balancing by the

15   method and apparatus of this invention as described above, the relative powers of the channels of the output signal from the amplifier 45 may all be substantially the same, as shown in Figure 7B at 48.

CLAIMS

1.   A method of controlling the relative amplitudes
of the individual wavelength components of a wavelength
division multiplexed optical signal, in which method
the wavelength division multiplexed optical signal is
5   processed through an adaptive optical wavelength
filter, the relative powers of each wavelength
component of the optical signal are determined, and a
complex control signal is supplied to the adaptive
optical wavelength filter which control signal includes
10   a control component for each wavelength component of
the multiplexed optical signal, the magnitude of each
control component being adjusted dependent upon the
determined power of the respective optical signal
wavelength component.

15   2.   A method as claimed in claim 1, wherein the
relative powers of the individual wavelength components
of the optical signal are determined following the
processing of the signal in the adaptive optical
wavelength filter.

20   3.   A method as claimed in claim 1 or claim 2,
wherein a portion of the optical signal is separated
into the individual wavelength components thereof, and
the power of each separated component is determined.

4.   A method as claimed in claim 3, wherein in-line
25   optical filters are employed to separate the portion of
the optical signal into individual wavelength
components.

5.   A method as claimed in claim 3, wherein a
wavelength division demultiplexer is employed to
30   separate the portion of the optical signal into
individual wavelength components.

6.   A method as claimed in claim 3, wherein an
adaptive optical wavelength filter is employed to
separate the optical signal into its individual
35   wavelength components, the output of the filter being

used to determine the power of each wavelength
component.

7.   A method as claimed in any of the preceding
claims, wherein the magnitude of each frequency
component of the control signal is adjusted such that
the relative powers of each wavelength component of the
optical signal are, after processing, substantially the
same.

8.   A method as claimed in any of claims 1 to 4,
wherein the magnitude of each frequency component of
the control signal is adjusted such that the relative
powers of each wavelength component of the optical
signal are, after processing, in a pre-set non-
identical relationship.

9.   A method as claimed in claim 8, wherein the pre-
set relationship is determined having regard to the
transfer function of a non-linear optical component in
which the optical signal is subsequently to be
processed.

10.   A method as claimed in any of the preceding
claims, wherein the adaptive optical wavelength filter
comprises one of an acousto-optic tunable filter and an
electro-optic tunable filter.

11.   A method as claimed in 10, wherein the adaptive
optical wavelength filter has primary and secondary
processed signal outputs, the determination of the
relative powers being performed on the secondary
processed output of the filter.

12.   A method as claimed in claim 11, wherein the
signal obtained from the secondary output is the
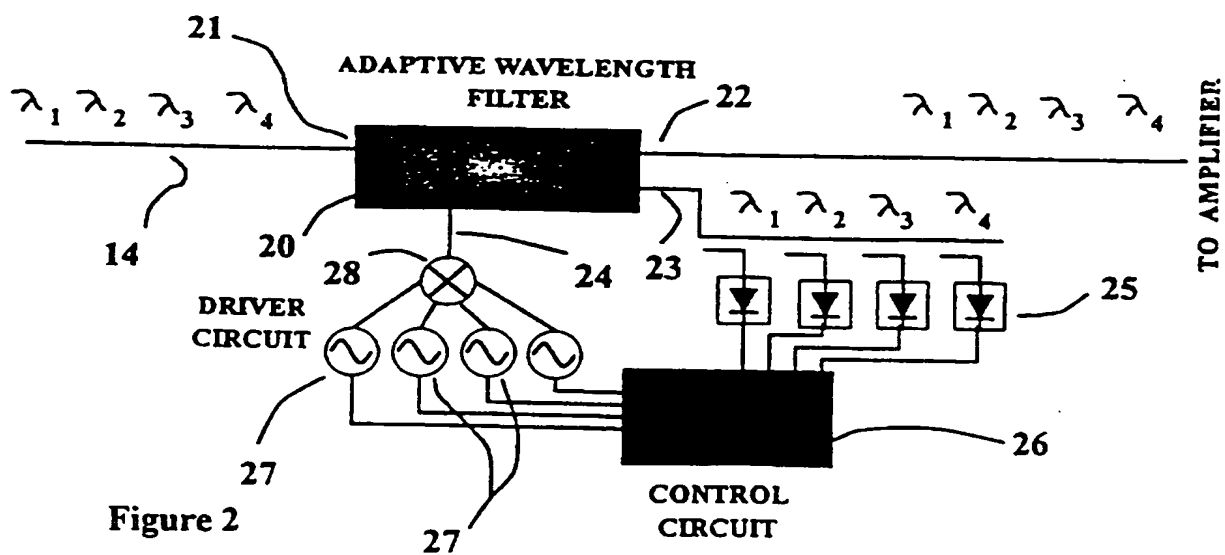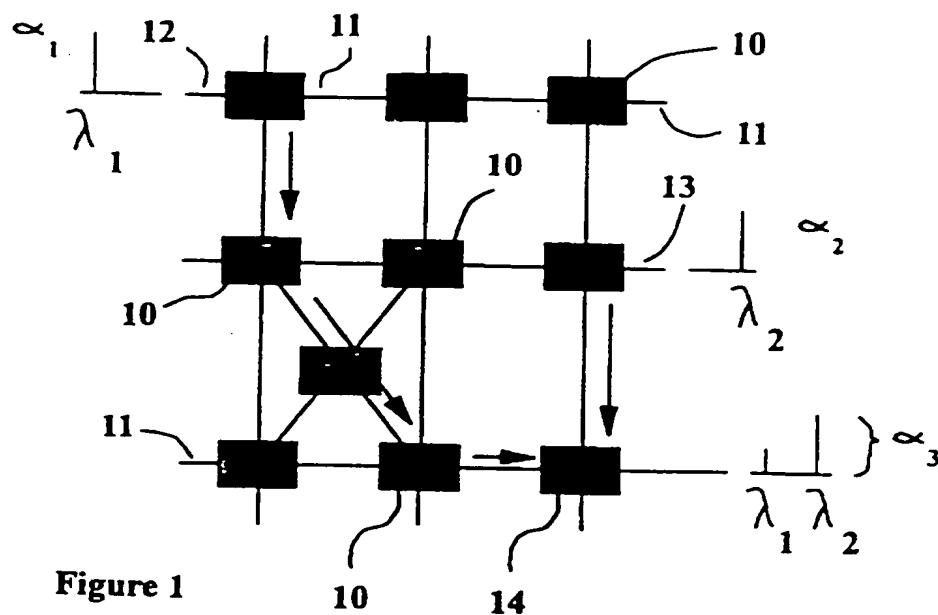inverse of the signal obtained from the primary output.

13.   Apparatus for controlling the relative
amplitudes of the individual wavelength components of a
wavelength division multiplexed optical signal, which
apparatus comprises an adaptive optical wavelength
filter through which the optical signal is passed for

processing therein, means to determine the relative powers of the wavelength components of the processed optical signal, control means responsive to the determined powers of each wavelength component and
5 providing a complex control signal to the adaptive optical wavelength filter which complex control signal includes a control component for each wavelength component of the multiplexed optical signal, the control means controlling the magnitude of each
10 control component dependent upon the determined power of the respective optical signal wavelength component.
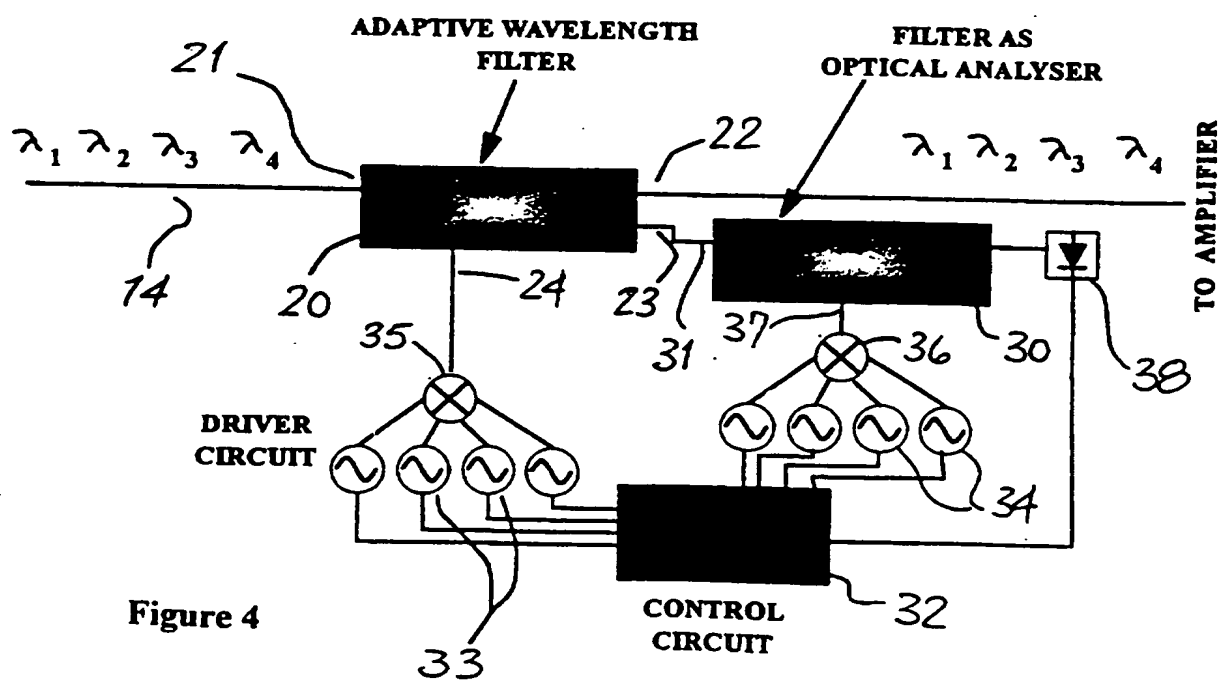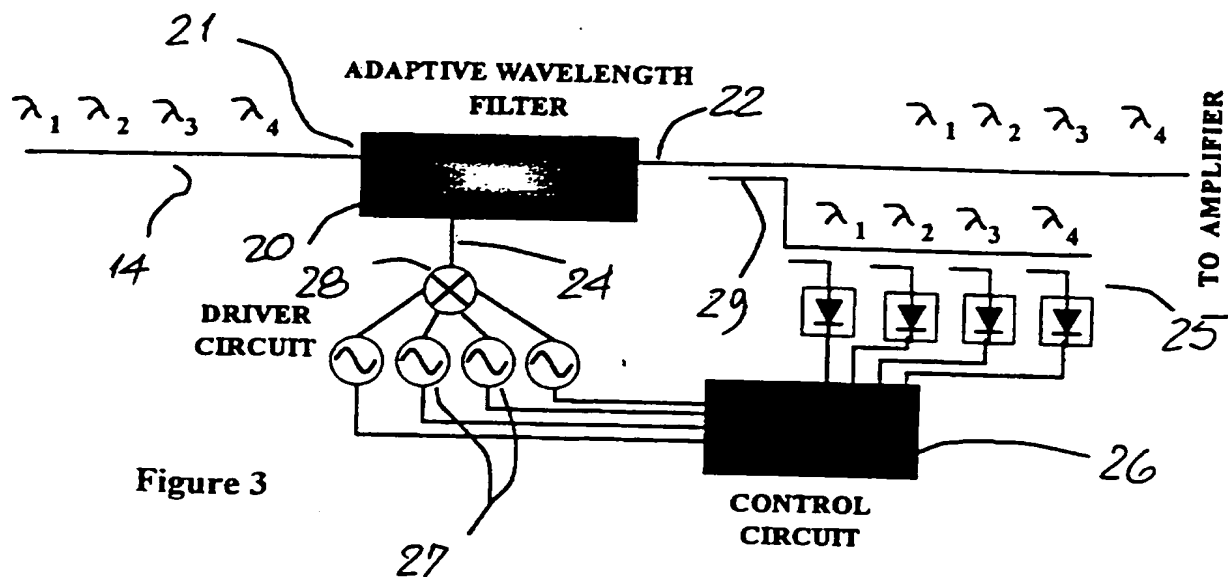
14.   Apparatus as claimed in claim 13, wherein said determining means includes separating means to separate each wavelength component of the wavelength division
15 multiplexed optical signal.

15.   Apparatus as claimed in claim 14 wherein said separating means comprises one of a plurality of in-line optical filters, a demultiplexer and a further adaptive optical wavelength filter.

Figure 1

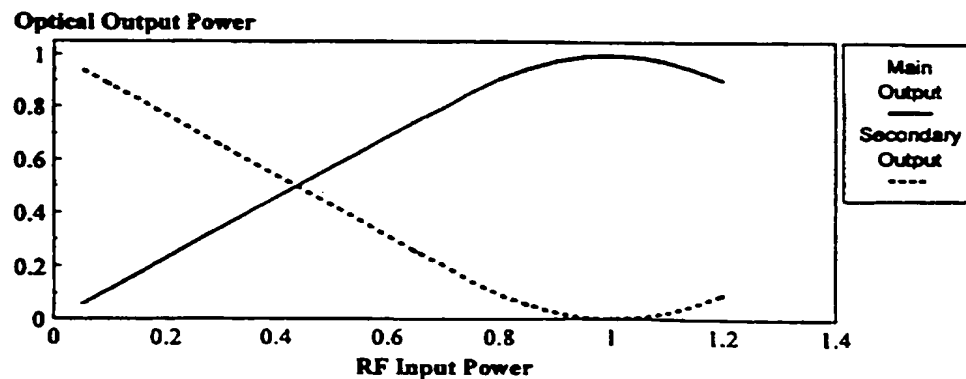Figure 2

Figure 3

Figure 4

3/4

ADAPTIVE WAVELENGTH   FILTER AS
FILTER   OPTICAL ANALYSER

Figure 5

DRIVER
CIRCUIT

CONTROL
CIRCUIT

TO AMPLIFIER

RF

Main Output

Secondary
Output

Optical Output Power

RF Input Power

Main
Output
——

Secondary
Output

Figure 6

Figure 7a

45

46

Conventional Optical Amplifier

47

Figure 7b

45

46

Optical Amplifier incorportating
Adaptive Balancing

48
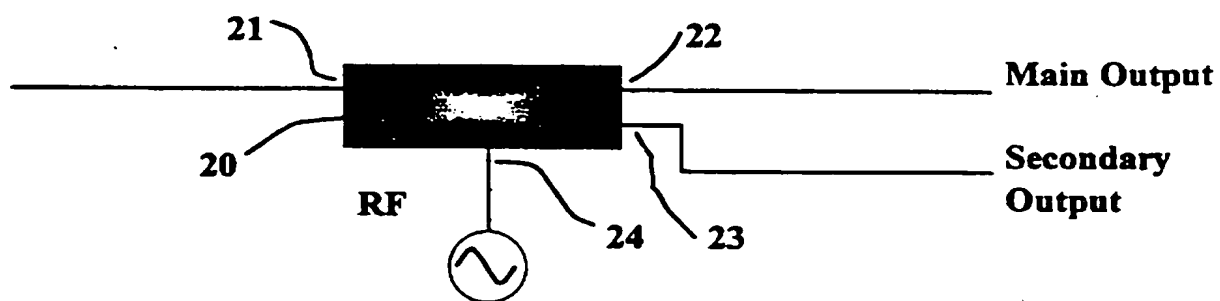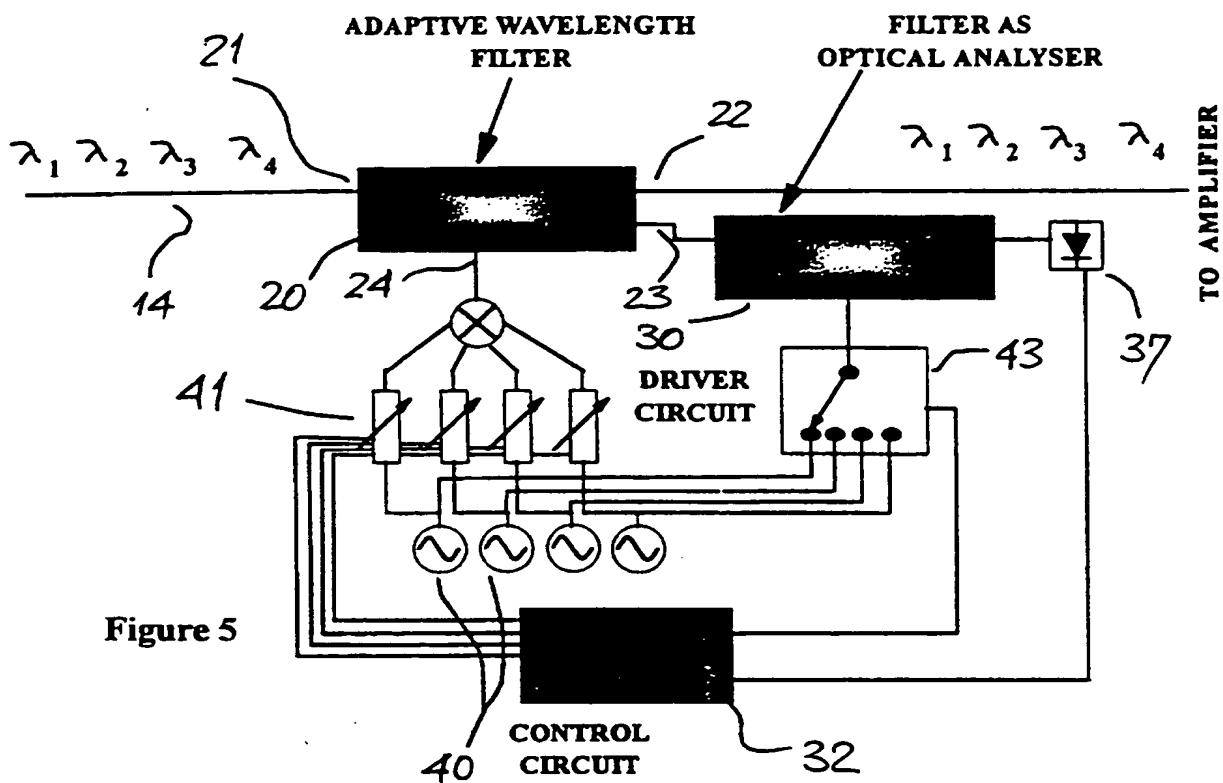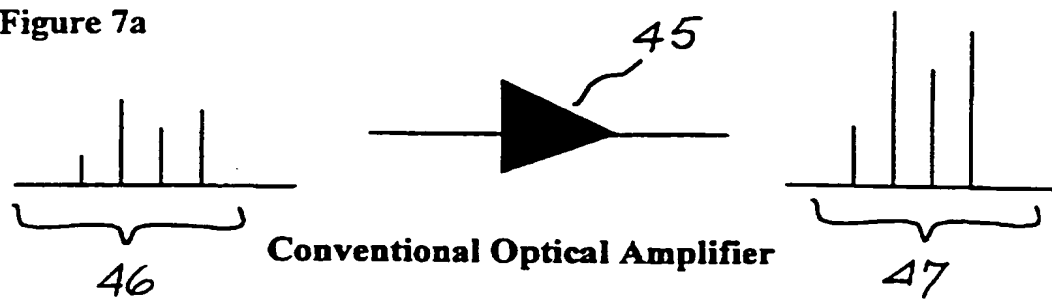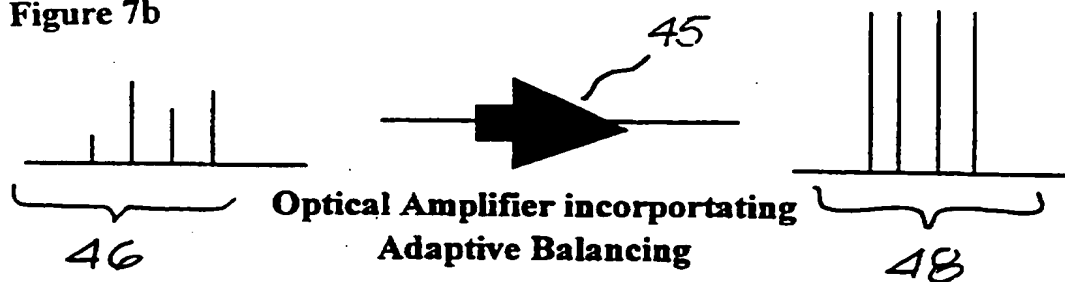
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   H04J   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 637 148 (NORTHERN TELECOM LTD) 1 February 1995	1,2,7-13
Y	see column 1, line 1 - column 2, line 5	3-6,14, 15
	see column 2, line 16 - column 3, line 35	
	see column 3, line 42 - column 4, line 1	
	see column 4, line 28 - line 31	

Y	EP,A,0 475 016 (HITACHI LTD) 18 March 1992	3-6,14, 15
	see abstract	
	see column 3, line 37 - column 4, line 9	
	see column 4, line 39 - line 58	

A	EP,A,0 467 396 (CANON KK) 22 January 1992 see abstract	1,2,13
	see column 2, line 1 - column 3, line 16	
	see column 5, line 1 - line 40	

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| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 1996	13.01.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl. Fax (+ 31-70) 340-3016	Chauvet, C

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IEE PROCEEDINGS J. OPTOELECTRONICS, vol. 140, no. 5, PART J, 1 October 1993, pages 275-284, XP000412788 WEBER J -P: "SPECTRAL CHARACTERISTICS BRAGG-REFLECTION TUNABLE OPTICAL FILTER" see abstract and introduction -----	10-12

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0637148	01-02-95	GB-A-	2280561	01-02-95
		US-A-	5463487	31-10-95
EP-A-0475016	18-03-92	JP-A-	4104634	07-04-92
EP-A-0467396	22-01-92	JP-A-	4078827	12-03-92
		US-A-	5396360	07-03-95

analyser section of the arrangement is taken from a passive tapping 29 on the main output from the filter. In all other respects this arrangement corresponds to that of Figure 2 and will not be described in further
5   detail here.

The third embodiment shown in Figure 4 employs a channel power analyser section utilising a second adaptive wavelength filter 30 the input port 31 of which is connected to the secondary output port 23 of
10 the principal adaptive filter 20. A single control circuit 32 controls the operation of two separate sets 33 and 34 of oscillators, the two sets of oscillators being associated with the two adaptive filters 20 and 30 respectively. The outputs of the
15 oscillators of each set are combined at 35 and 36 respectively and the resultant control signals are supplied to the control ports 24 and 37 respectively, of the two adaptive filters 20 and 30.

The output of the adaptive filter 30 is supplied
20 to a single photo-detector 38 and the signal indicative of the power of the channel component instantaneously supplied to the photo-detector 38 is fed to the control circuit 32, in order to control the appropriate oscillator of the set 33 associated with the filter 20.
25 In this way, the powers of the various wavelengths in the signal leaving the main output port of the filter 20 may be balanced as required, with the analysis of the powers of the channels being performed using the further adaptive filter 30 for sampling the channels
30 one at a time, in sequence, under the control of circuit 32. By using a single control circuit 32, the operation of the embodiment may properly be synchronised to ensure that the transfer function of the filter 20 for each channel is properly matched to
35 the detected power of that channel.

Figure 5 illustrates a further embodiment similar